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RESEARCH MEMORANDUM

EFFECT OF FUEL INJECTOR LOCATION AND MIXTURE CONTROL ON PERFORMANCE OF A 16-INCH RAM-JET CAN-TYPE COMBUSTOR

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

July 29, 1953

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EFFECT OF FUEL INJECTOR LOCATION AND MIXTURE CONTROL ON PERFORMANCE OF A 16-INCH RAM-JET CAN-TYPE COMBUSTOR

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SUMMARY

A 16-inch connected-pipe investigation was undertaken to evaluate an existing can-type combustor configuration and to develop this configuration to give a wide operable fuel-air ratio range of high combustion efficiency. Only fuel-injector changes were investigated. Without increasing the combustor cold-flow pressure-drop coefficient of 1.5, acceptable performance was achieved by providing the combustor with a fuel-injection system in which a mixture control sleeve was added upstream of the flame holder to provide a locally stoichiometric mixture at lean as well as rich over-all fuel-air ratios. Combustion efficiencies from 92 to 97 percent were obtained with MIL-F-5624A grade JP-4 fuel over a fuel-air ratio range from 0.012 to 0.056 (the rich limit of the facility) at conditions corresponding to flight at a Mach number of 2.9 and an altitude of 67,000 feet.

A comparison is made between the connected-pipe burner performance and the performance of one of the injector configurations which had previously been evaluated during a study of a 16-inch ram-jet engine at a Mach number of 2.0 in the Lewis 8- by 6-foot supersonic wind tunnel.

INTRODUCTION

A ram-jet combustor design and development program is under way at the NACA Lewis laboratory to establish design principles for ram-jet combustors and to reduce these principles to practical application. Among the general combustor types being considered in this program is the can-type combustor, for its performance characteristics encourage its application to the ram-jet engine (refs. 1 and 2). The principle upon which this general type of combustor is based has been used successfully with other combustor designs (refs. 3, 4, and 5) and involves combining local mixture control with a large-volume shielded primary combustion zone.

A can-type combustor was recently employed in a supersonic wind-tunnel evaluation of a 16-inch ram-jet engine of NACA design (ref. 6). These tests were run at a maximum Mach number of 2.0 and a combustor-inlet-air temperature of 160° F. The combustor exhibited little sensitivity to angle of attack and to subcritical diffuser operation, both desirable combustor features. However, it was found necessary to use propylene oxide as the fuel because combustion with gasoline was unsatisfactory.

In the wind-tunnel study, the combustor-inlet temperature was nearly 100° F below that which would be experienced in flight at a Mach number of 2.0 and very much below that which would result in higher flight-speed applications. The connected-pipe investigation was undertaken at a higher temperature, namely 600° F, and at a pressure of about 1 atmosphere. These conditions simulate a Mach number of 2.9 at 67,000-feet altitude. This investigation was conducted to evaluate the existing can-type combustor configuration and to optimize the configuration to give a wide operable fuel-air ratio range of high combustion efficiency. The results are reported herein, and a comparison is made with some previously unreported supersonic-wind-tunnel data.

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APPARATUS AND PROCEDURE

8- by 6-Foot Wind Tunnel Tests

A schematic diagram of the 16-inch ram-jet engine with which the can-type-combustor data were obtained in the 8- by 6-foot supersonic wind tunnel is shown in figure 1. Details of the engine dimensions and installation in the tunnel test section are given in reference 6. The engine consisted of a diffuser 9.34 feet long and a combustion chamber and nozzle 6.25 feet long. The supersonic diffuser was so designed that the oblique shock generated by the 25° half-angle conical spike would fall slightly ahead of the cowl lip at a free-stream Mach number of 1.8.

Pilot burner. - A pilot burner was used with a blend of 50-percent propylene oxide and 50-percent clear gasoline. The fuel was sprayed through a nozzle rated at 12.5 gallons per hour at a differential pressure of 100 pounds per square inch.

Flame holder and fuel injector. - The can-combustor flame holder used in this study had a surface open area of 133 percent of the combustion-chamber cross-sectional area. The can was rigidly fastened at its upstream end to the pilot burner. Spacers, which permitted relative movement between the can and the combustion-chamber wall, were provided for rear support. Diagrams of the flame holder and the fuel injection arrangements investigated in this phase of the program are shown in figures 2(a) and (b). The flame holder had a cold-flow pressure-drop coefficient of 1.5.

Combustion efficiency. - Combustion efficiency is defined as the ratio of the change in energy of the gases flowing through the engine to the lower heating value of the fuel injected. The changes in gas energy were computed from pressure measurements made with a water-cooled total-pressure rake located at the engine outlet. The engine air flows and combustor-inlet Mach numbers based on the annular area at the diffuser exit were computed from previously calibrated internal-pressure instruments. The heat lost through the engine shell was neglected in the efficiency calculations.

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Connected-Pipe Tests

The engine and test installation used in the connected-pipe tests are shown in figure 3.

Flame holder and fuel injectors. - The flame holder and the fuel injector arrangement investigated initially were the same as in the wind-tunnel tests (fig. 2(a)). Subsequent fuel-injector modifications are discussed in conjunction with their effect on combustion performance and are shown in figures 2(c) to (i).

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Fuel. - The properties of the two fuels, MIL-F-5624A grade JP-4 and clear gasoline, used as both primary and pilot fuels, are given in table I.

Operating conditions. - The ram-jet combustor was operated over the following inlet conditions:

Inlet-air static pressure, in. Hg abs	32 to 36
Inlet-air temperature, $^{\circ}F$	590 to 610
Inlet-air velocity, ft/sec	230 to 260

These values correspond to the combustor-inlet conditions in a ram-jet engine at a flight Mach number of 2.9, at an approximate altitude of 67,000 feet, and with a diffuser total-pressure recovery of 70 percent.

Combustion efficiency. - Combustion efficiencies were determined by a heat-balance system similar to the method outlined in reference 3. Combustion efficiency is defined as the ratio of the enthalpy change of fuel, air, quench water, and engine cooling water to the heating value of the fuel input. At a given engine operating condition, the quench-water flow was adjusted to a value insuring complete vaporization of the water, and outlet temperatures of 600° to 900° F were maintained at the thermocouple station. Negligible heat loss from the ducting downstream of the water spray was assumed.

RESULTS AND DISCUSSION

Wind-Tunnel Tests

Because the objective of the wind-tunnel tests was a performance study of a complete ram-jet engine with emphasis on aerodynamic data, little effort was spent in combustor development. The data reported herein were at a flight Mach number of 2.0, an altitude of 38,000 feet, and a combustor-inlet temperature of 160° F.

As indicated in reference 6, the can-type combustor, when operated with propylene oxide fuel, exhibited little sensitivity to angle of attack in the range from 0° to 10° and to subcritical diffuser operation. Both characteristics are exhibited by few ram-jet combustors; therefore, additional interest was created in the can-type combustor for ram-jet application.

The first attempt to burn clear gasoline with the can-type combustor (fig. 2(a)) at a Mach number of 2.0 was unsuccessful, although previously the same combustor configuration had been successfully operated on propylene oxide (ref. 6). With an uncontracted exit nozzle, burner ignition could not be obtained with either clear gasoline or a blend of 50-percent clear gasoline and 50-percent propylene oxide even though the pilot burner had been ignited and was burning satisfactorily.

To increase the residence time and to provide for better atomization and vaporization of the fuel, the injection system was modified as indicated in figure 2(b) (configuration B). A manifold containing 12 equally spaced commercial spray nozzles, each rated at 60 gallons per hour, was added to the existing fuel system. This manifold was located 12 inches upstream of the pilot-burner exit and the fuel was injected counter to the air flow. Approximately two-thirds of the total fuel flow was introduced through the added injectors.

With an uncontracted outlet (nozzle area ratio, 1.0), the engine could now be operated on the fuel blend. However, burning with clear gasoline alone, even preheated to 220° F and flash vaporized, proved erratic. Only when the combustor-inlet velocity was reduced by contracting the engine outlet (nozzle area ratio, 0.71) could the engine be ignited and operated with reasonable success on preheated gasoline. The data thus obtained are given in figure 4. It is clear that the operable fuel-air ratio range is narrow, 0.029 to 0.043, and the resulting efficiencies are low.

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Connected-Pipe Tests

Initial tests were undertaken with a combustor similar to configuration A used in the wind-tunnel phase of this investigation. Only slight differences in combustor length and in the subsonic portion of the engine inlet diffuser were involved. Based upon the performance obtained, several successive changes were made in the injector arrangement and the burner configuration was optimized, configurations C to I (figs. 2(c) to (i)). The several fuel-injector configurations employed are discussed in the order of their evaluation. Neither rich nor lean operation was ever limited by blow-out, but rich operation was restricted by the capacity of the water spray used in determining the combustion efficiency, while lean operation was limited by the ability of the spray to quench the reaction and still evaporate ahead of the thermocouple station. Gasoline in amounts not exceeding 5 percent of the total fuel flow was burned in the pilot burner in all the tests. The main fuel was MIL-F-5624A grade JP-4, except as noted.

<u>Internal fuel injection</u>. - The original fuel injector employed in the wind-tunnel tests injected the fuel internally, within the can flame holder. Two separate fuel manifolds were used, an upstream or primary manifold and a downstream or secondary manifold (fig. 2(a)). With only primary injection, combustion efficiencies of approximately 95 percent were obtained over the fuel-air ratio range from 0.0135 to 0.037 (fig. 5). Above 0.037, the combustion efficiency decreased as the fuel-air ratio was raised, dropping to a value of 37 percent at a fuel-air ratio of 0.07. A combination of primary and secondary injection resulted in a similar trend. Moreover, changing the fuel from JP-4 to the more volatile clear gasoline resulted in negligible effect on combustion performance, thus indicating that at this high inlet-air temperature condition, fuel volatility was not the critical variable affecting combustion efficiency in the rich fuel-air ratio region.

The performance of configuration A operating on JP-4 fuel or clear gasoline at a simulated Mach number test condition of 2.9 is compared in figure 6 with the performance previously obtained in wind-tunnel tests at a Mach number of 2.0 with propylene oxide.

Considerable difference in the combustion efficiencies was noted. This disagreement between the two sets of data may be due to some of the following differences in the two installations:

(1) The subsonic diffuser (figs. 1 and 3)

(2) Inlet-air temperature

(3) Fuel type

It is not apparent which of these variables is controlling. It is interesting to note that in both cases the same general trend of a reduction in combustion efficiency as fuel-air ratio was raised is observed. This was attributed to local overenrichment of the flow in the region of the fuel injectors as operation at the richer fuel-air ratios was attempted.

Upstream fuel injection. - In an effort to raise the combustion efficiency at the richer fuel-air ratios by improving the mixture of the air and fuel, the point of fuel injection was moved to a station 17 inches upstream of the can. Two upstream injector configurations C 2940
and D (figs. 2(c) and (d)) were used. The six nozzle injectors (configuration C) were rated at 0.5 gallon per minute at a pressure differential of 100 pounds per square inch. The 16 nozzles (configuration D) were rated at 0.36 gallon per minute at the same pressure differential. The effect of fuel-air ratio and injector radial position on combustor performance with configuration C is indicated in figure 7(a) and with configuration D in figure 7(b). With both configurations, a definite trend was noted with injector radial position: lean operation was improved with fuel injection near the diffuser centerbody, whereas better rich operation resulted as the injector radius was increased. With the fuel injected $2\frac{5}{16}$ inches from the outer wall, combustion efficiencies of 90 percent or greater were observed at fuel-air ratios of 0.035 to 0.054. Little effect of number of injection points, 6 or 16, was noted.

Combined upstream and internal fuel injection. - The results obtained separately with upstream and internal fuel injection indicated that efficient combustion should result over a wide fuel-air ratio range by combining the two systems in a single configuration. Internal injection would give efficient lean operation, and upstream injection would give efficient rich operation. Data obtained by combining the two injection systems (configuration E, fig. 2(e)) are shown in figure 7(c). Internal fuel injection was held constant at a fuel-air ratio of 0.015 (ratio of primary fuel to total air flow), and additional fuel was introduced through the upstream injector. Combustion efficiencies ranging from 87 to 95 percent were observed over a fuel-air ratio range from 0.015 to 0.055. Structural failure of the can prevented completion of the tests and the obtaining of additional data. Subsequent examination showed that burnout was caused because the air scoop and the manifold supplying the internal fuel were acting as a flame holder upstream of the can.

A comparison is made in figure 8 of the results obtained with internal fuel injection, upstream fuel injection, and a combination of these systems, configurations A, D ($2\frac{5}{16}$-in. radial position), and E, respectively. It is apparent that a fuel system which maintains a locally

stoichiometric mixture is desired for lean operation. For rich operation, a homogeneous stoichiometric mixture gives best results. By appropriately combining the two systems, their advantages are combined. It is possible to schedule the two injectors of the combined system so they may be operated with a single throttle or control element. However, for the purpose of study and evaluation, independent control was maintained over the flow through each of the two injectors in this as well as in all subsequent tests of the combined system.

2940 <u>Combined fuel injection with mixture control sleeve</u>. - The preliminary results obtained with the combined injection system encouraged a more complete evaluation of this injector-flame-holder combination, and the combustor was redesigned to avoid future can failure due to upstream burning. Modifications consisted of removal of the small air scoop in the region of the internal fuel injector and installation of a control sleeve to provide an aerodynamically clean passage for the flow of secondary air-fuel mixture around the internal or primary injector, as shown in figure 2(f) (configuration F). The addition of this sleeve eliminated fuel from the wake of the primary-injector manifold which is located outside of the can, thus avoiding a flame seat upstream of the can.

The performance of this modified combustor configuration F is indicated in figure 9(a). The results confirmed the performance observed with the initial attempt at combined injection, and the combustion efficiencies obtained were in general similar. The effect of the primary fuel-air ratio on combustion efficiency over the rich fuel-air ratio range was investigated, and it was determined that low primary flows were desirable. A 22-percent drop in combustion efficiency was observed at an over-all fuel-air ratio of 0.05 as the primary fuel-air ratio was raised from 0.014 to 0.034. No difficulty with flame-holder burnout or failure was encountered, and the cold-flow burner pressure loss was not measurably increased.

<u>Internal and secondary injection in same axial position</u>. - In an effort to reduce the drop in combustion efficiency at the fuel-air ratios where the secondary fuel is initially introduced, approximate fuel-air ratio of 0.02 to 0.03, and simultaneously to minimize the effect of the primary fuel-air ratio on the combustion efficiency at the higher over-all fuel-air ratios, the control sleeve was eliminated. At very lean fuel-air ratios, the control sleeve accomplished the desired result. However, in the transition region between primary alone and combined injection, the confining action of the sleeve caused over-enrichment in the primary zone. The removal of the control sleeve was intended to provide a more gradual transition region between primary alone and combined injection than the abrupt transition accompanying the use of the sleeve. In addition, the secondary fuel injector was

relocated to the same axial position as the primary or internal injector. The spray from the secondary simple-orifice injector was directed in such a manner as to avoid fuel impingement and flame seating on the manifold of the primary injector. Figure 2(g) shows the resulting configuration G.

The results obtained with configuration G are shown in figures 9(b) and (c). Primary-fuel flows and radial-injection distances were varied to determine the optimum operating procedure for this configuration. The best combinations of primary-fuel flow and radial-injector position gave combustion efficiencies of 90 percent or better over the fuel-air ratio range from 0.011 to 0.049. This represented an improvement over con- 2940
figuration F in the transition region of fuel-air ratios from 0.02 to 0.03. A secondary-injector radial distance of $1\frac{3}{4}$ inches from the outer wall (midway in the annular passage) was found to give best results. However, the large sensitivity of combustion efficiency at the richer over-all fuel-air ratios to the primary fuel-air ratio was still observed. It was also apparent that the combustion efficiency, especially in the transition region, was affected by the radial position of the secondary injector.

Dual upstream injection. - Although some gains in performance in the transition region were attained by removal of the mixture control sleeve, additional improvement was desired. A further reduction in the abrupt change of mixture concentration in the transition region would result by the use of an upstream injector location which allows a longer period for fuel-air mixture preparation. It was also believed that upstream injection would reduce the sensitivity of the combustor to the primary fuel-air ratio, because variations in upstream fuel concentrations do not necessarily produce corresponding variations in the combustor primary zone. Therefore, instead of internal injection, the primary fuel for lean operation was introduced through six equally spaced nozzle injectors placed along the centerbody and located 17 inches upstream of the can. Secondary fuel was injected through 16 equally spaced nozzles placed in the middle of the annular air passage and also located 17 inches upstream of the can. Figure 2(h) shows the resulting configuration H.

The results obtained with configuration H are summarized in figure 9(d). The combustion efficiency was 90 percent or greater over the fuel-air ratio range from 0.022 to 0.055. In addition, the drop of combustion efficiency in the transition region as well as the sensitivity to primary fuel-air ratio was essentially eliminated. Below a fuel-air ratio of 0.022 the combustion efficiency dropped sharply, reaching a value of 75 percent at a fuel-air ratio of 0.011.

Dual upstream injection with mixture control sleeve. - To improve the efficiency at fuel-air ratio less than 0.022, a mixture control sleeve was employed to raise the local mixture concentration in the region of the flame holder at lean over-all fuel-air ratios (configuration I, fig. 2(i)). This sleeve was $9\frac{1}{2}$ inches in diameter and separated the primary and secondary air and fuel flows. Primary fuel was injected into the inner annulus, and secondary fuel was injected into the outer annulus.

The resulting performance of configuration I is indicated in figure 9(e). The combustion efficiency at lean fuel-air ratios was improved considerably by the addition of the sleeve, and combustion efficiencies between 92 and 97 percent were attained over the fuel-air ratio range from 0.012 to 0.056. Facility limitations prevented operation at richer fuel-air ratios.

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Adding the sleeve increased the sensitivity of the burner to the primary-injector flow rate over that previously observed without the sleeve (configuration H, fig. 9(d)). However, the variation in combustion efficiency with primary fuel-air ratio was considerably less than with configurations F and G (figs. 9(a) to (c)). The performance characteristics of the dual injector system indicates that the primary-fuel injector should be used alone at fuel-air ratios less than 0.02. For richer operation the primary-fuel flow should be held at a constant overall fuel-air ratio value of 0.02 or less.

CONCLUDING REMARKS

The desired wide operable fuel-air ratio range of high combustion efficiency was considered achieved with configuration I and further research on this combustor was curtailed. Without increasing the original cold-flow burner pressure-loss coefficient of 1.5 the principle of maintaining a locally stoichiometric mixture over the entire fuel-air ratio range was designed into the burner. A control sleeve technique was successfully applied to the can flame holder for mixture control at lean over-all fuel-air ratios. The final configuration evolved yielded combustion efficiencies between 92 to 97 percent at fuel-air ratios from 0.012 to 0.056. Facility limitations prevented operation at both richer and leaner fuel-air ratios.

Additional research with other facilities is needed to investigate the effect of inlet-air pressure and temperature, angle of attack, and subcritical diffuser operation on the performance of this burner configuration.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, May 25, 1953

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2. Bennet, W. J., and Maloney, S.: Altitude Tests of the Convair 20 Inch Can Type Combustor. Rep. No. 2M-9136-010, Consolidated Vultee Aircraft Corp., San Diego (Calif.), May 10, 1950.

3. Cervenka, A. J., Bahr, D. W., and Dangle, E. E.: The Effect of Fuel-Air Ratio Concentration in Combustion Zone on Combustion Performance of a 16-Inch Ram-Jet Engine. NACA RM E53B19, 1953.

4. Cervenka, A. J., and Dangle, E. E.: Effect of Fuel-Air Distribution on Performance of a 16-Inch Ram-Jet Engine. NACA RM E52D08, 1952.

5. Dangle, E. E., Cervenka, A. J., and Bahr, D. W.: Effects of Fuel Temperature and Fuel Distribution on the Combustion Efficiency of a 16-Inch Ram-Jet Engine at a Simulated Flight Mach Number of 2.9. NACA RM E52J14, 1953.

6. Perchonok, Eugene, Wilcox, Fred, and Pennington, Donald: Effect of Angle of Attack and Exit Nozzle Design on the Performance of a 16-Inch Ram Jet at Mach Numbers from 1.5 to 2.0. NACA RM E51G26, 1951.

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TABLE I. - SPECIFICATIONS AND ANALYSIS OF PRIMARY ENGINE FUELS,

MIL-F-5624A GRADE JP-4 AND CLEAR GASOLINE

	Specifications, MIL-F-5624A	Analysis	
		MIL-F-5624A	Gasoline
A.S.T.M. distillation D 86-46, °F			
Initial boiling point		137	106
Percentage evaporated			
5		204	132
10	250 (max.)	248	148
20		288	172
30		309	194
40		323	213
50		335	233
60		348	249
70		360	267
80		378	286
90		408	308
Final boiling point	550 (max.)	480	362
Residue, percent	1.5 (max.)	1.2	1.2
Loss, percent	1.5 (max.)	0.8	1.3
Specific gravity, °A.P.I.	40 (min.), 58 (max.)	0.765	0.714
Reid vapor pressure, lb/sq in.	2.0 (min.), 3.0 (max.)	50.6 2.7	66.7 6.8
Hydrogen-carbon ratio		0.168	0.182
Net heat of combustion, Btu/lb	18,400 (min.)	18,675	18,925

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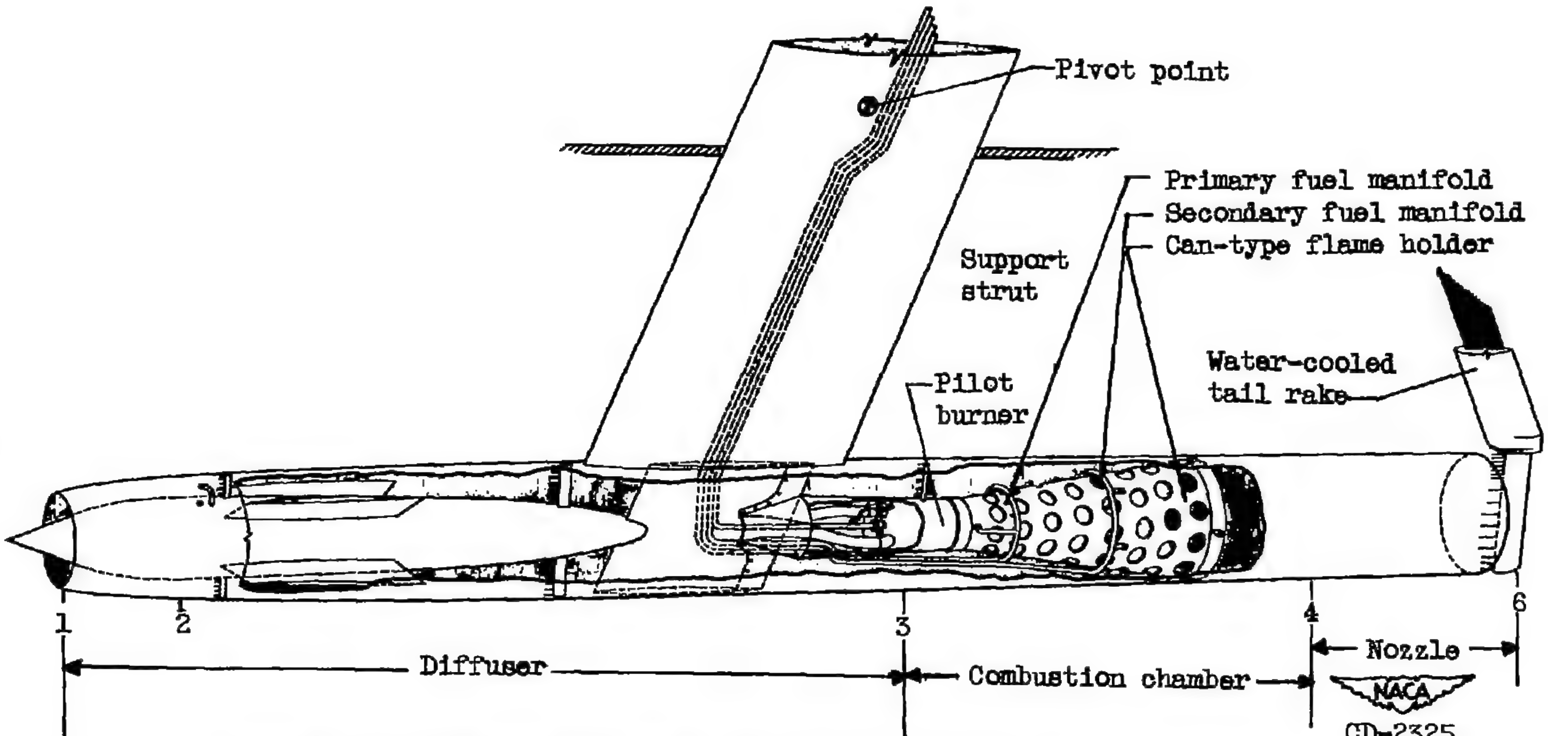
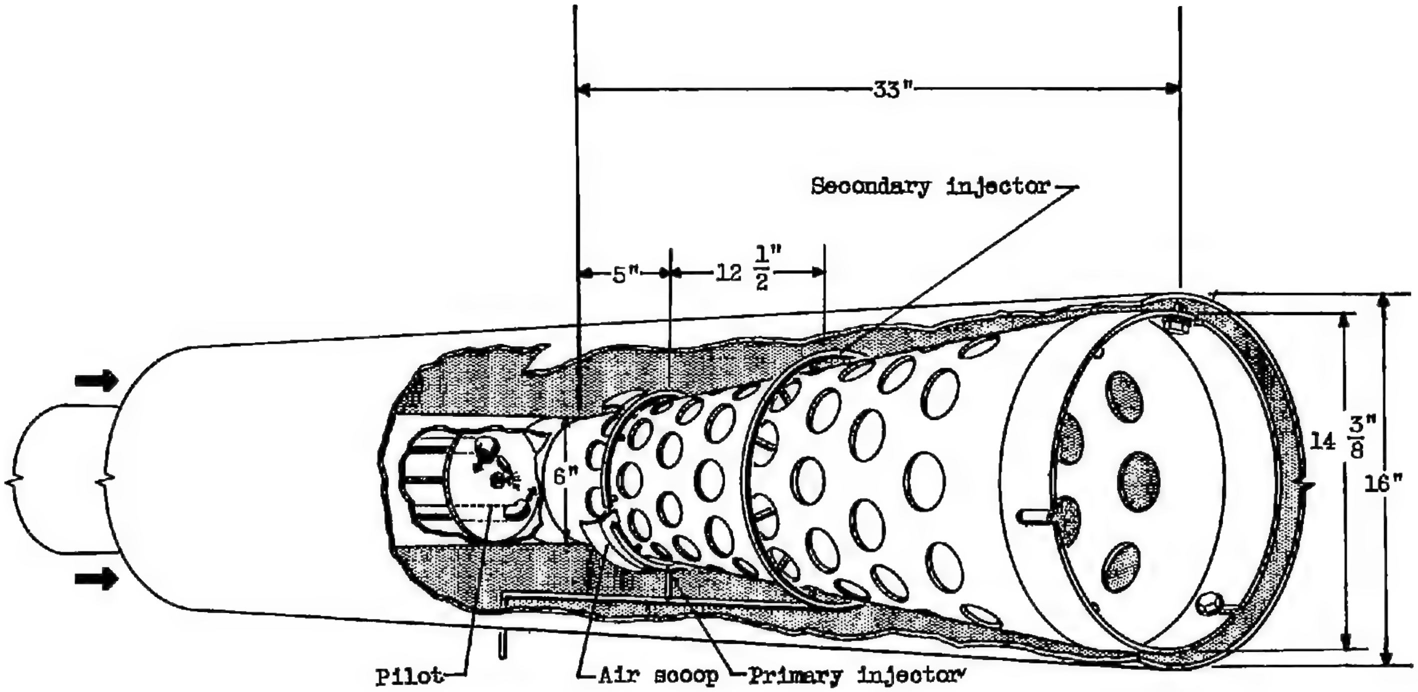
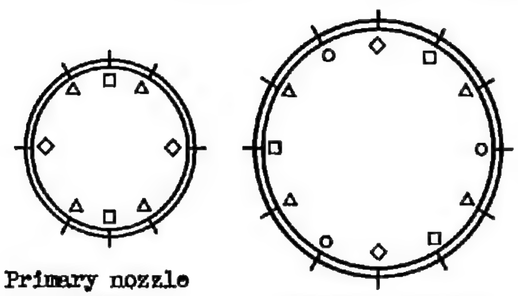


Figure 1. - Diagrammatic sketch of 16-inch ram-jet engine





Nozzle spray	Spray direction	Nozzle rating at 100 lb/sq in., gal/min	
		Primary manifold	Secondary manifold
○ Conical	Radial	0.667	1.000
□ Conical	45° Upstream		
◇ Conical	45° Downstream		
△ Flat	Downstream	.625	0.625

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(a) Configuration A.

Figure 2. - Fuel-injector configurations.

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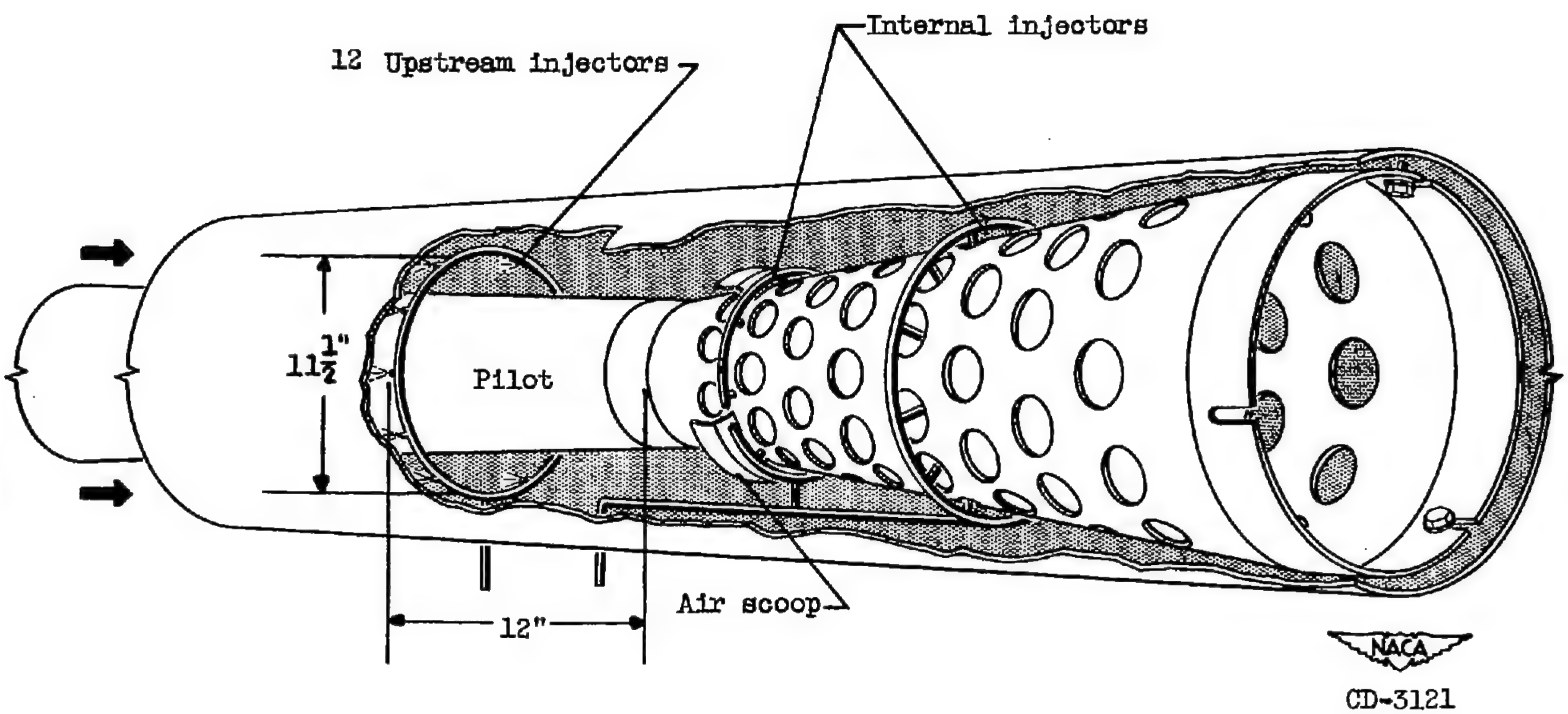

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(b) Configuration B.

Figure 2.- Continued. Fuel-injector configurations.

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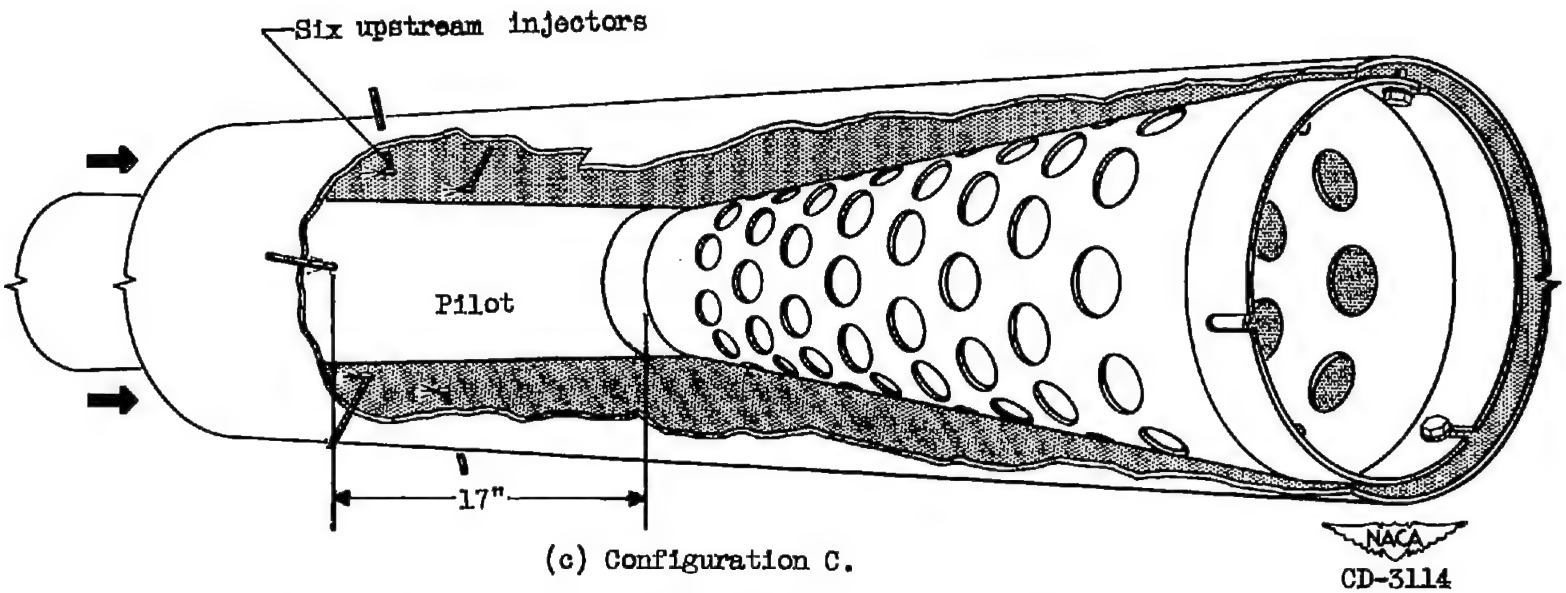
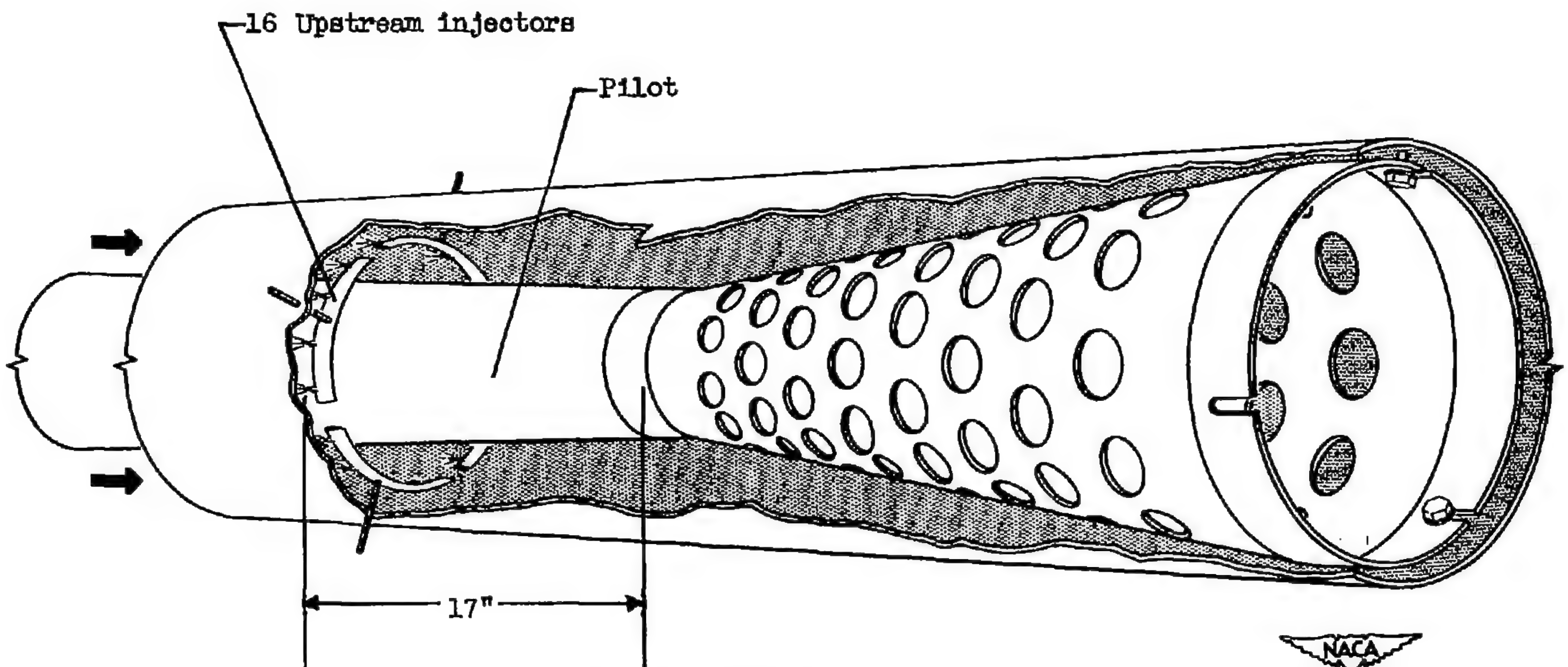


(c) Configuration C.

Figure 2. - Continued. Fuel-injector configurations.



(d) Configuration D.

Figure 2. - Continued. Fuel-injector configurations.

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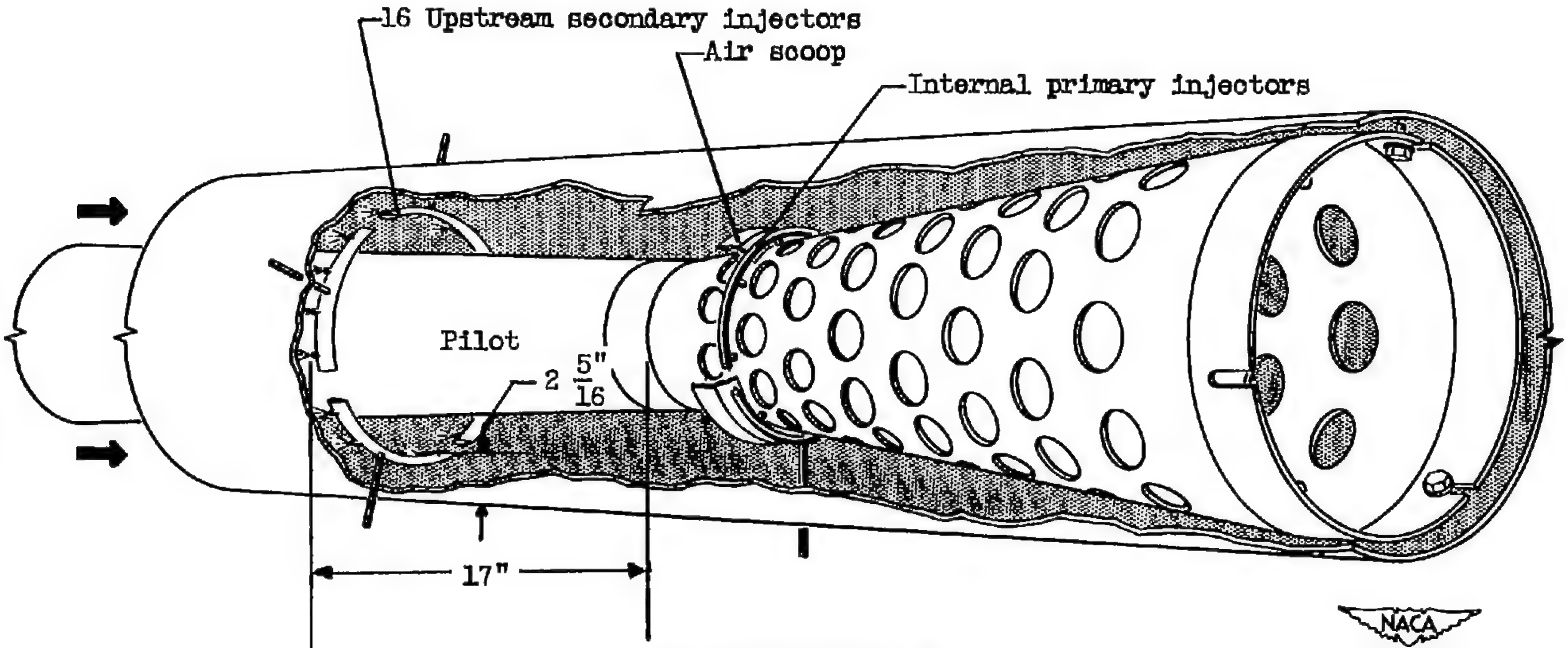

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(e) Configuration E.

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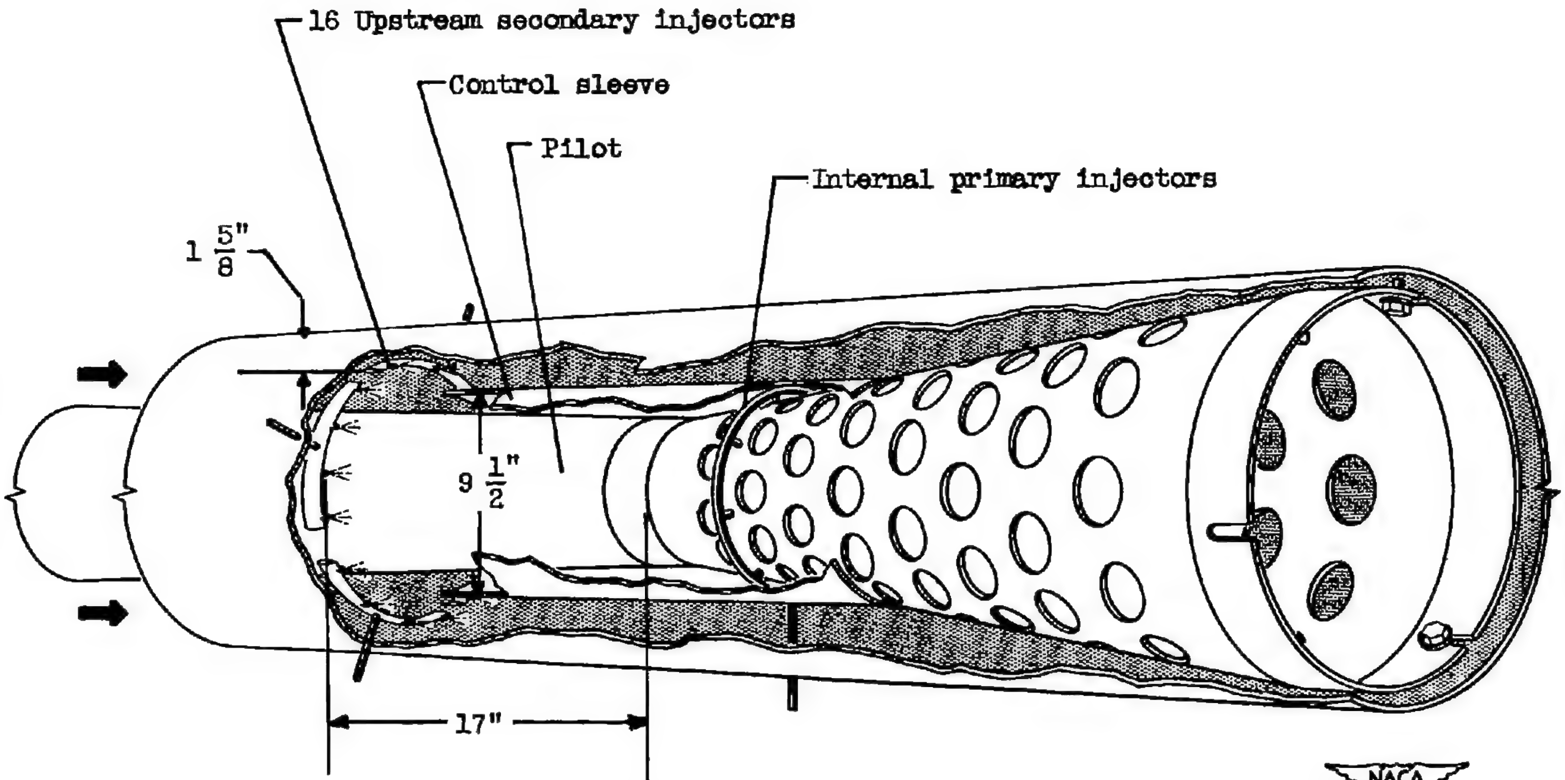
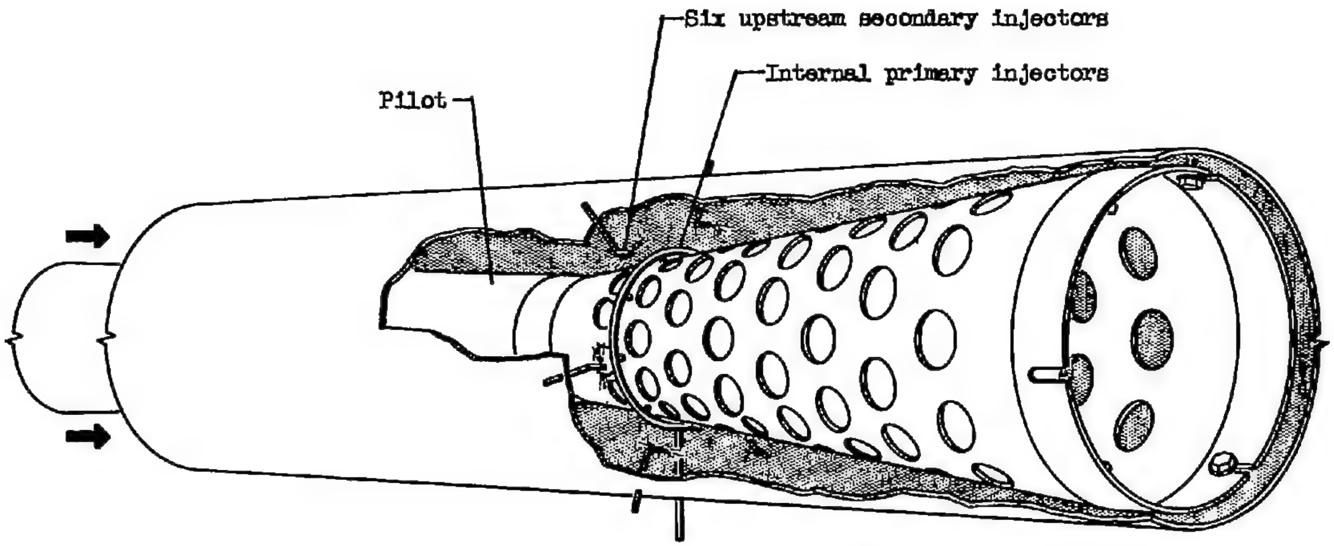
Figure 2. - Continued. Fuel-injector configurations.



(f) Configuration F.

Figure 2. - Continued. Fuel-injector configurations.



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(g) Configuration G.

Figure 2. - Continued. Fuel-injector configurations.

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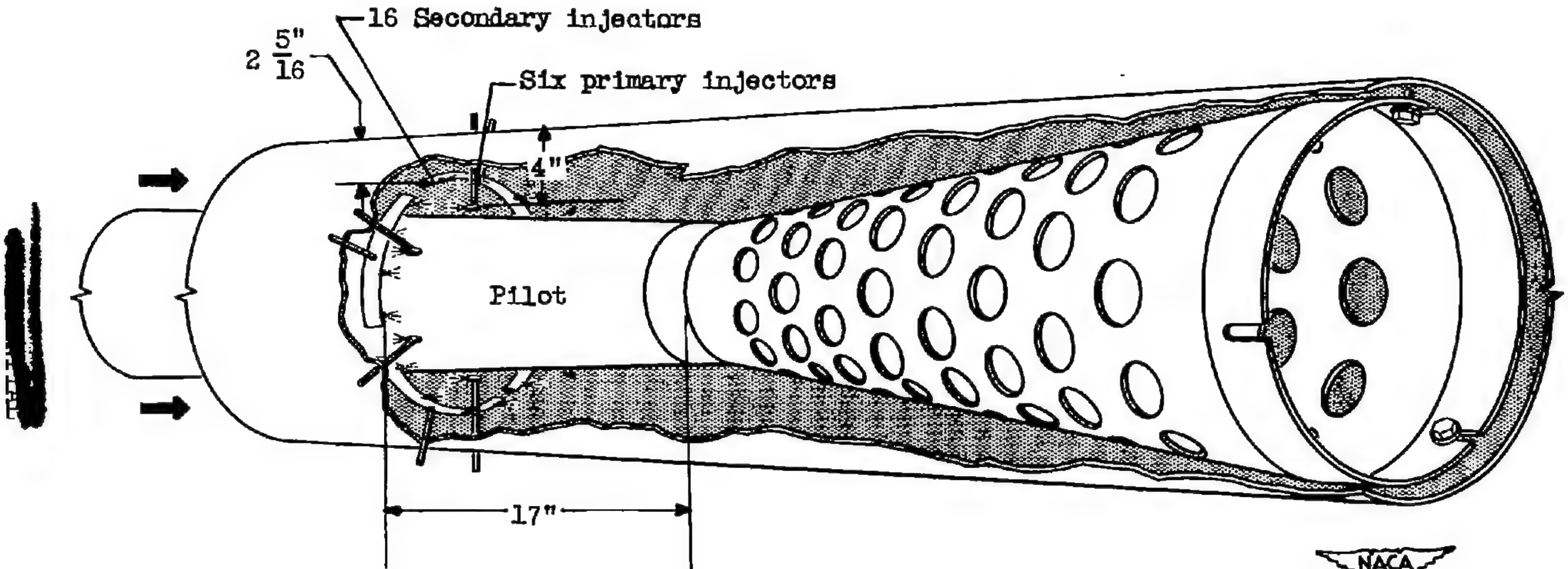

(h) Configuration H.

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Figure 2. - Continued. Fuel-injector configurations.

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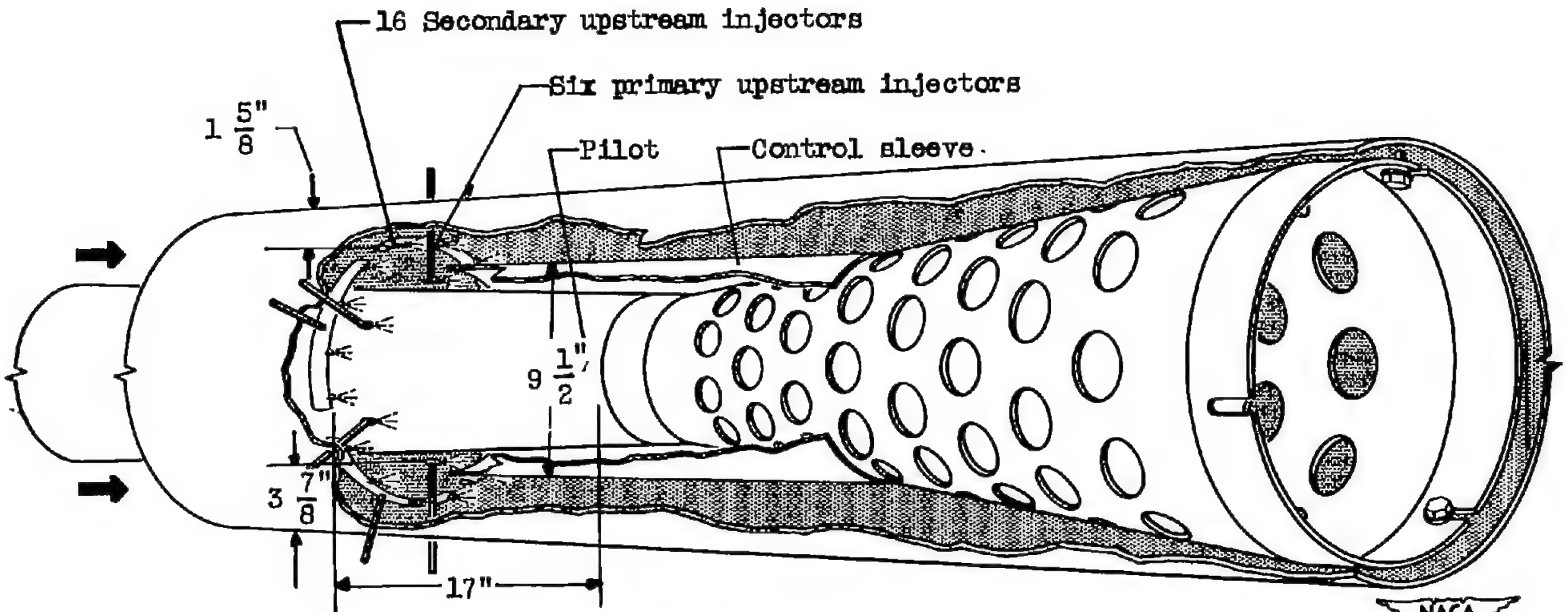

(i) Configuration I.

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Figure 2. - Concluded. Fuel-injector configurations.

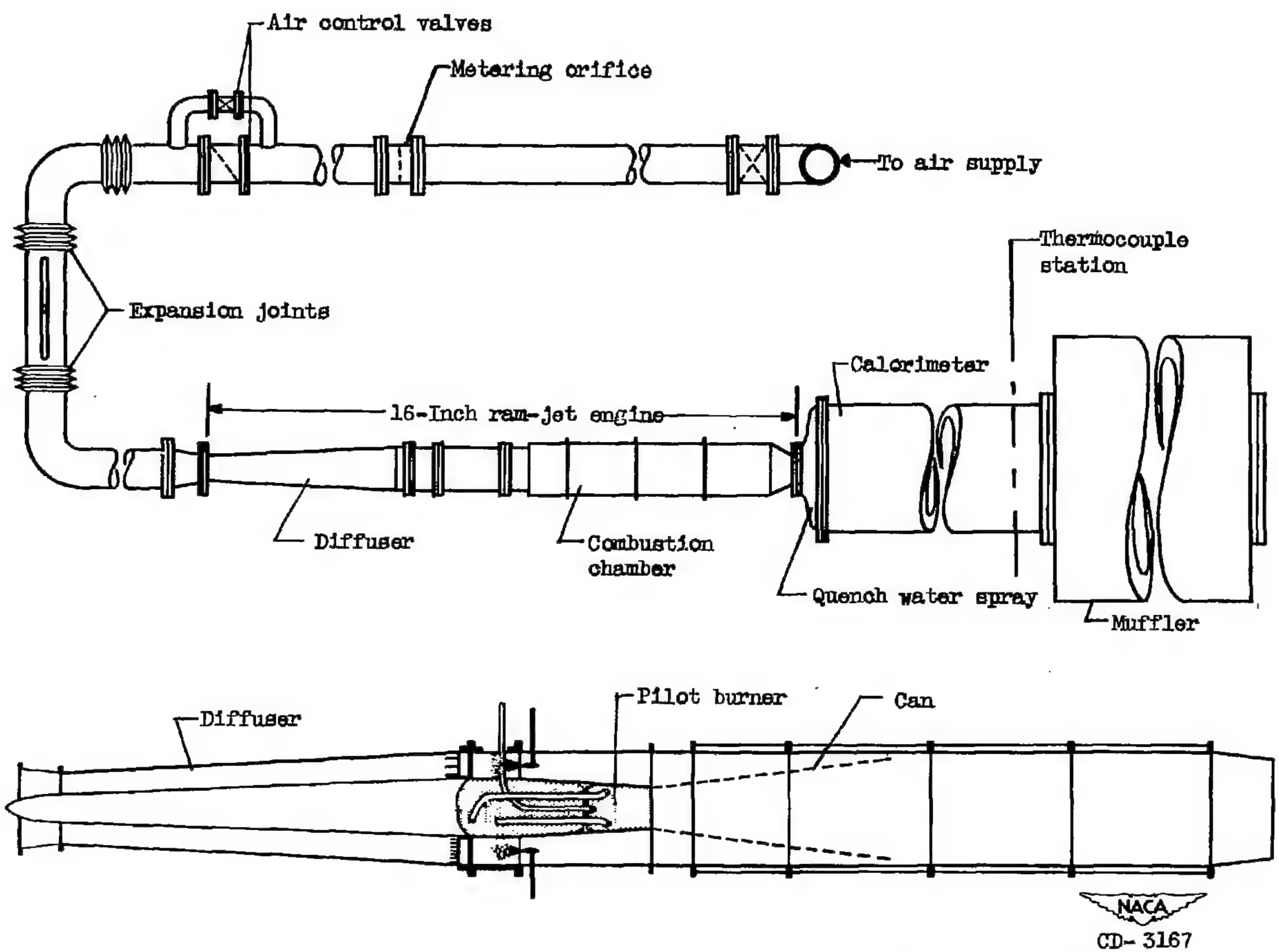

Figure 3. - Installation of 16-inch ram-jet engine used in connected-pipe tests.

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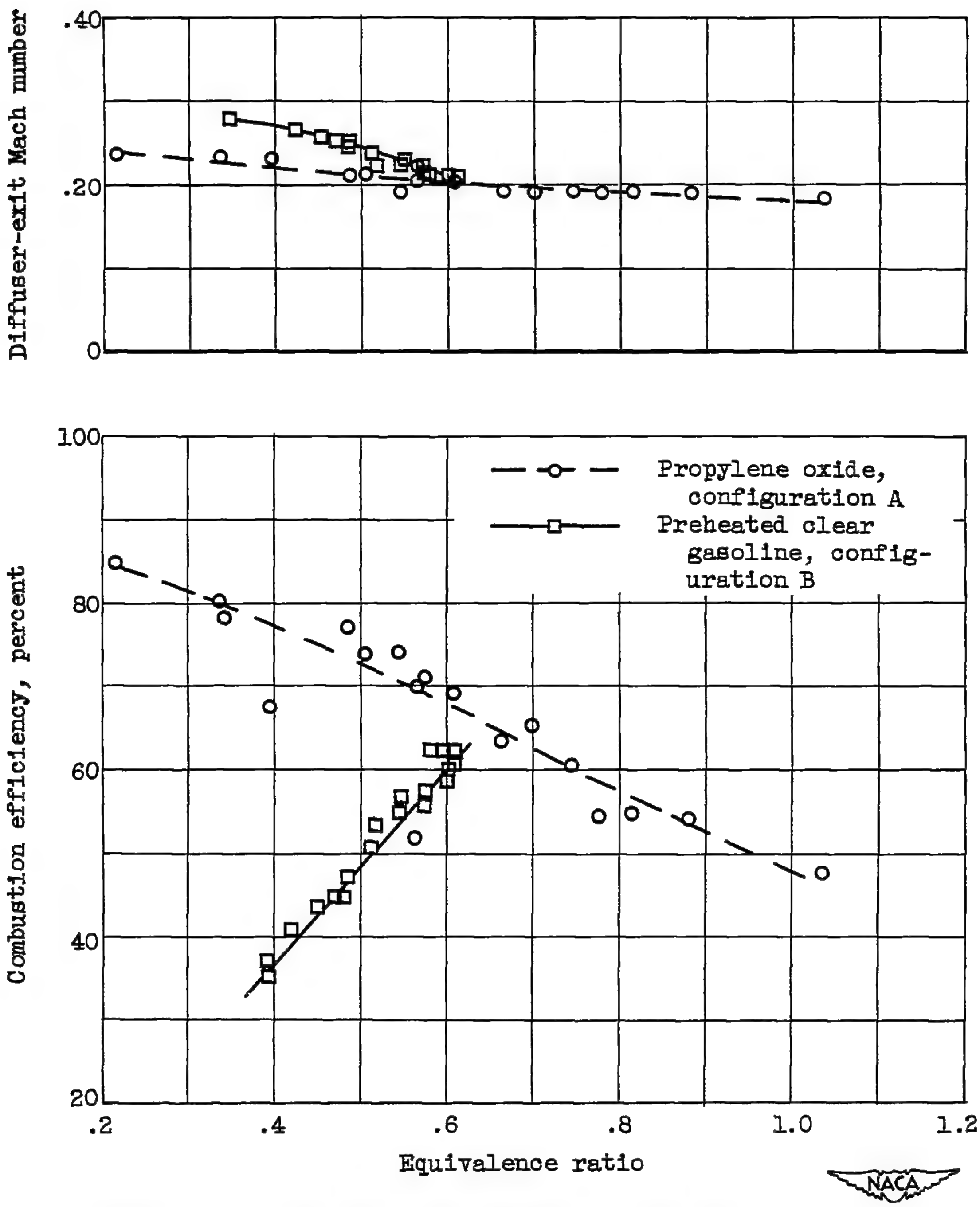

Figure 4. - Combustor performance of configurations A and B with clear gasoline and propylene oxide in supersonic wind-tunnel tests. Flight Mach number, 2.0; angle of attack, 0°; converging nozzle; stoichiometric fuel-air ratio: clear gasoline, 0.066; propylene oxide, 0.106.

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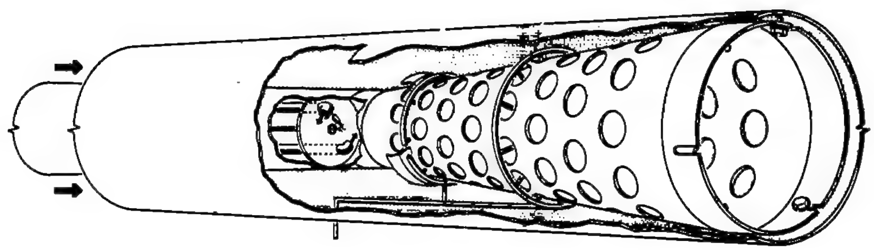

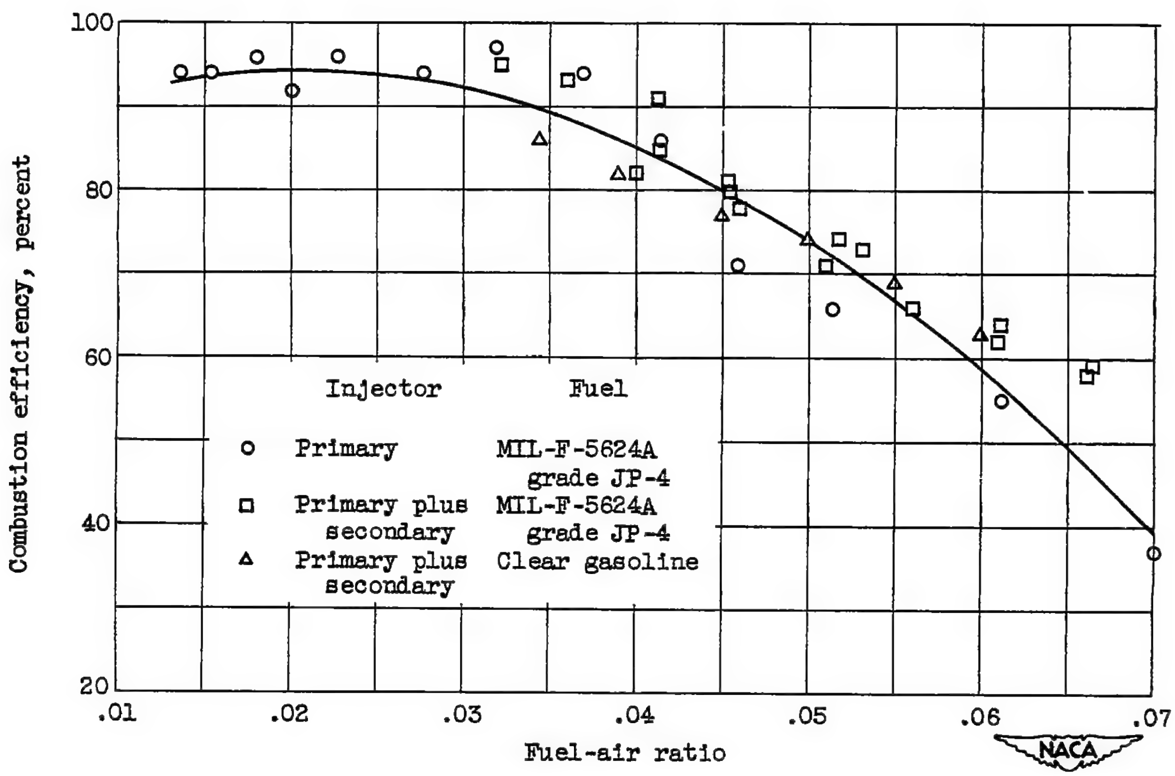

Figure 5. - Combustor performance of configuration A. Inlet-air temperature, 590° to 610° F; velocity, 230 to 260 feet per second; pressure, 32 to 36 inches of mercury absolute.

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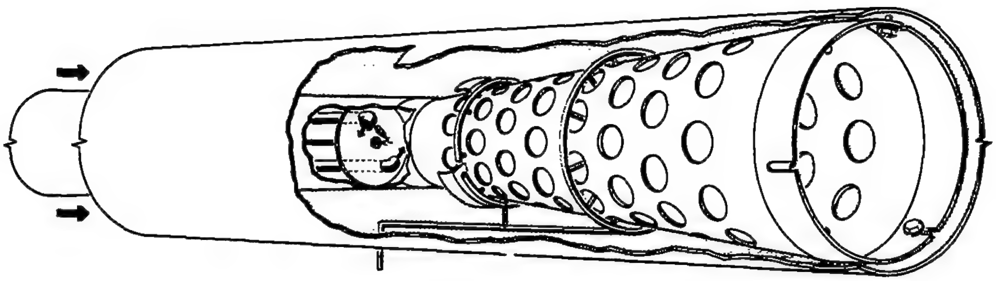

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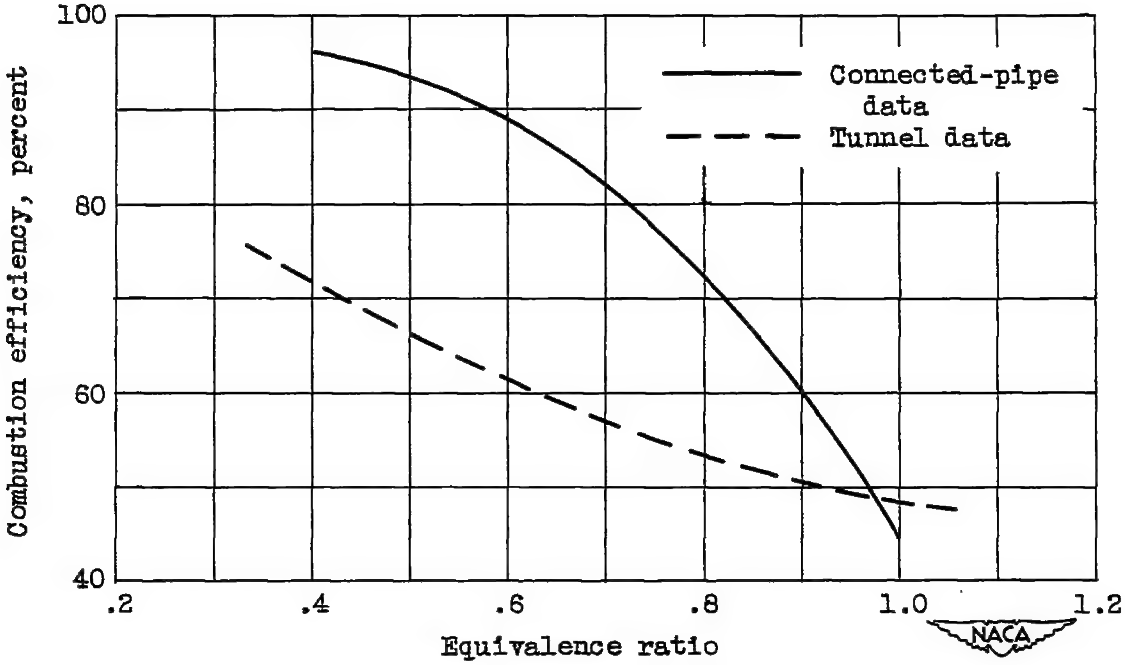

Figure 6. - Comparison of connected-pipe and wind-tunnel data for configuration A. Tunnel data: flight Mach number, 2.0; pressure, 34 to 40 inches of mercury absolute; inlet-air temperature, 160° F; velocity, 185 to 235 feet per second; fuel, propylene oxide; equivalence ratio, 0.106. Connected-pipe data: flight Mach number, 2.9; pressure, 32 to 36 inches of mercury absolute; inlet-air temperature, 590° to 610° F; velocity, 230 to 260 feet per second; fuel, MIL-F-5624A grade JP-4; equivalence ratio, 0.066.

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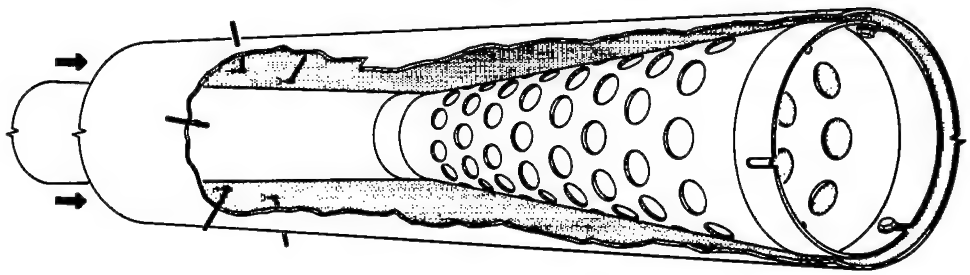
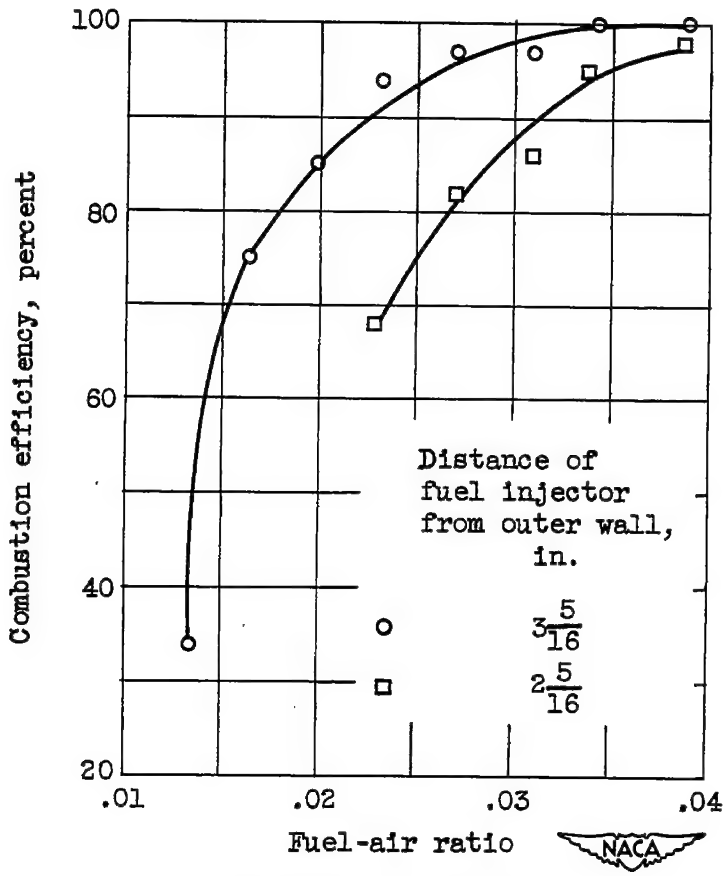
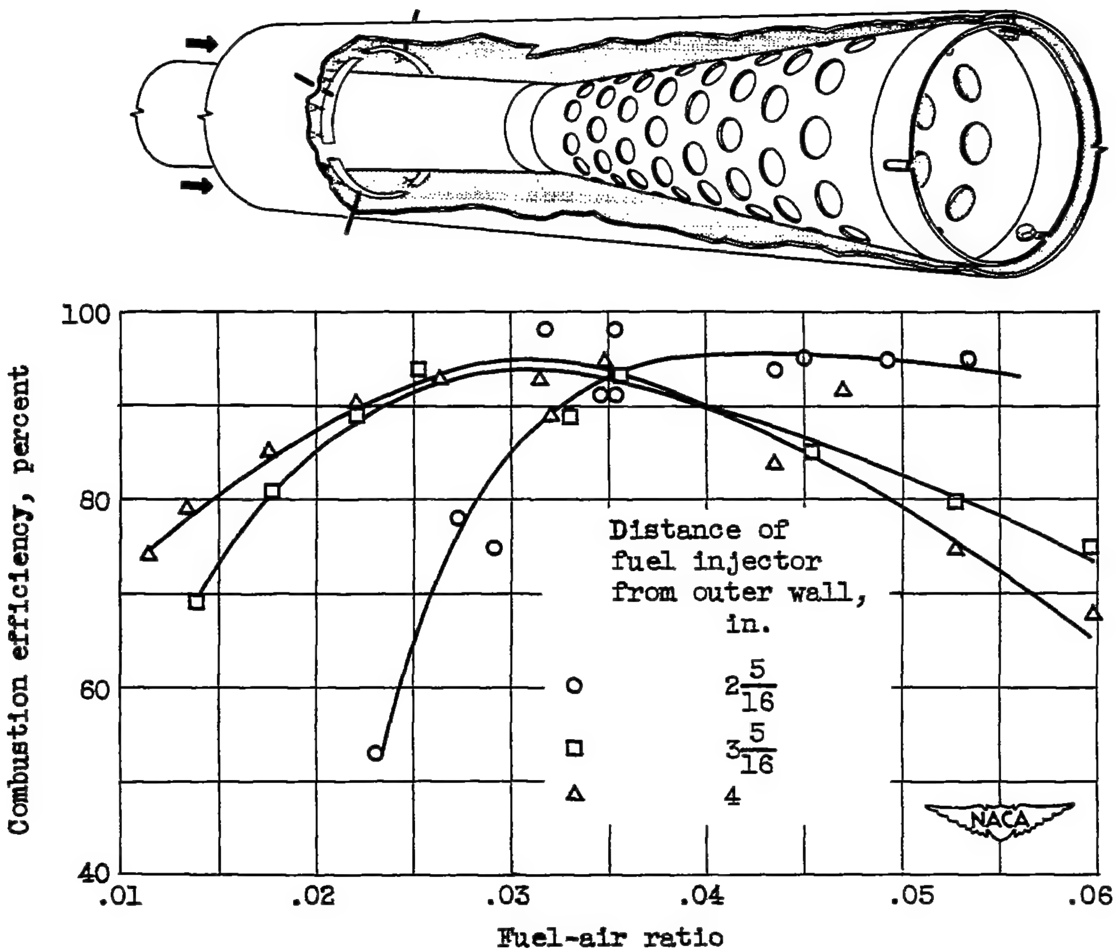




(a) Configuration C.

Figure 7. - Combustor performance of configurations C, D, and E with MIL-F-5624A grade JP-4 fuel. Inlet-air temperature, 590° to 610° F; velocity, 230 to 260 feet per second; pressure, 32 to 36 inches of mercury absolute.



(b) Configuration D.

Figure 7. - Continued. Combustor performance of configurations C, D, and E with MIL-F-5624A grade JP-4 fuel. Inlet-air temperature, 590° to 610° F; velocity, 230 to 260 feet per second; pressure, 32 to 36 inches of mercury absolute.

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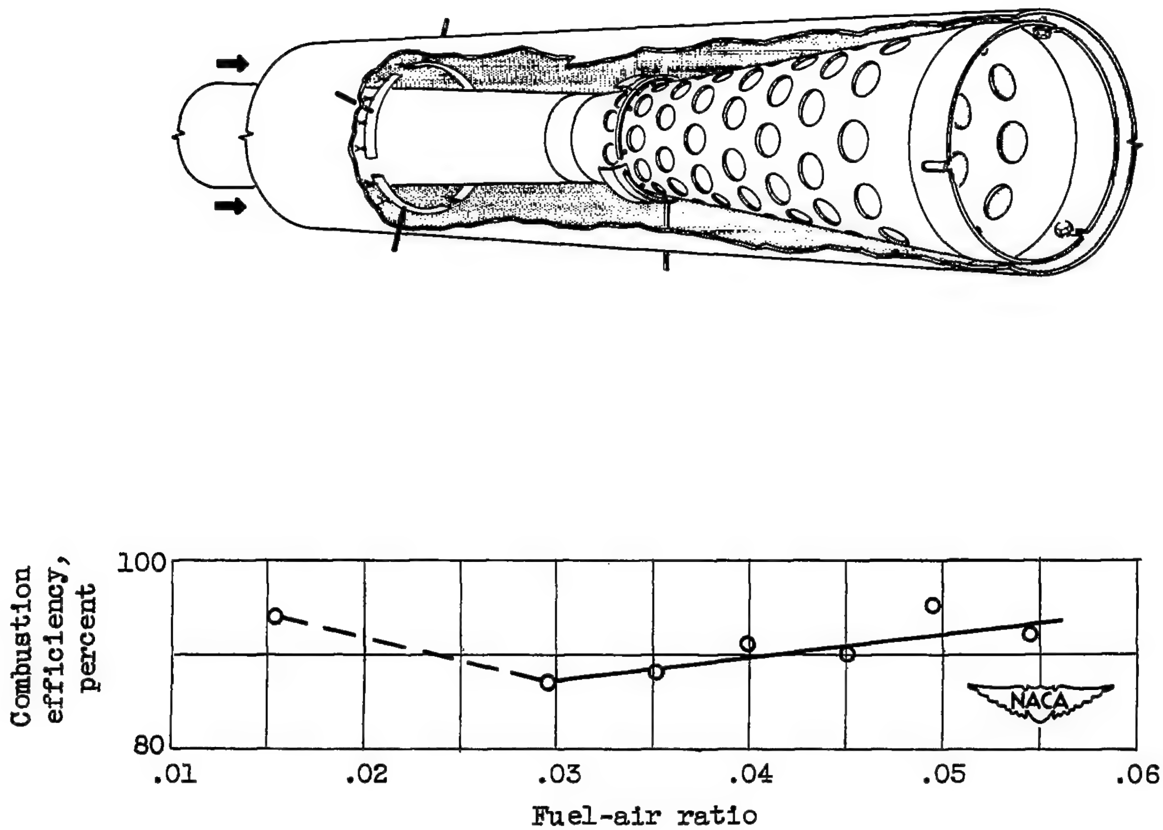

(c) Configuration E.

Figure 7. - Concluded. Combustor performance of configurations C, D, and E with MIL-F-5624A grade JP-4 fuel. Inlet-air temperature, 590° to 610° F; velocity, 230 to 260 feet per second; pressure, 32 to 36 inches of mercury absolute.

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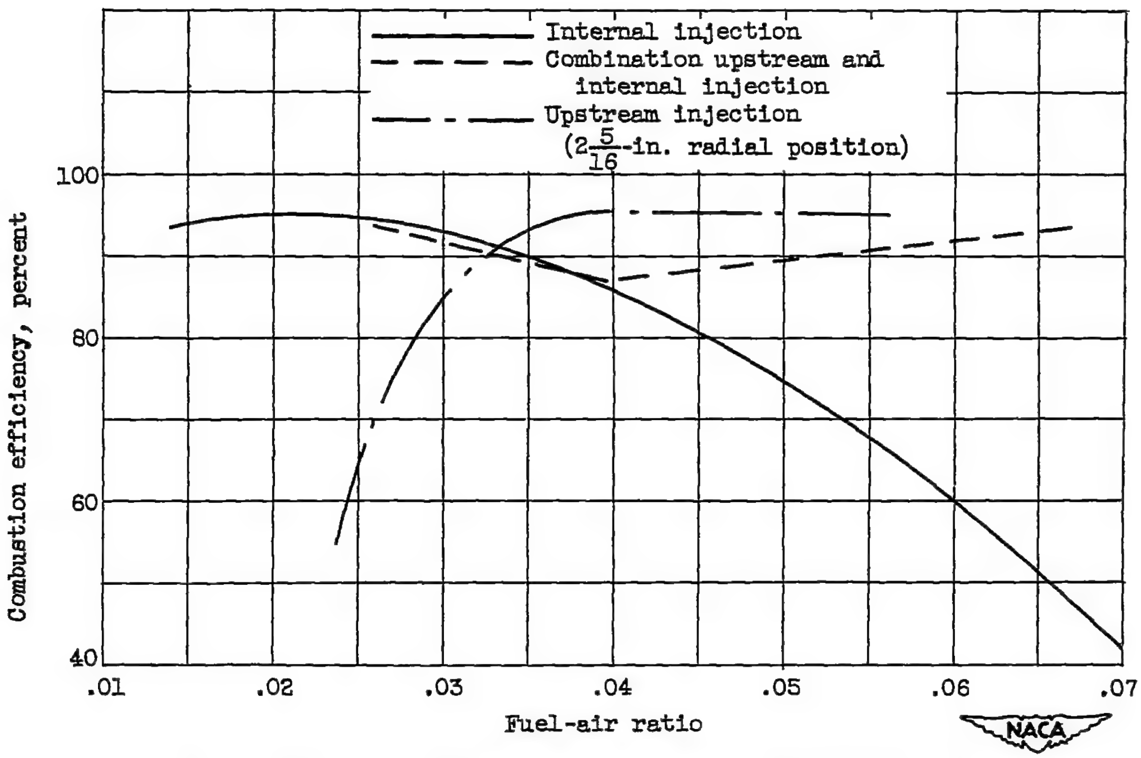

Figure 8. - Comparison of combustor performance of configurations A, D, and E with MIL-F-5624A grade JP-4 fuel. Inlet-air temperature, 590° to 610° F; velocity, 230 to 260 feet per second; pressure, 32 to 36 inches of mercury absolute.

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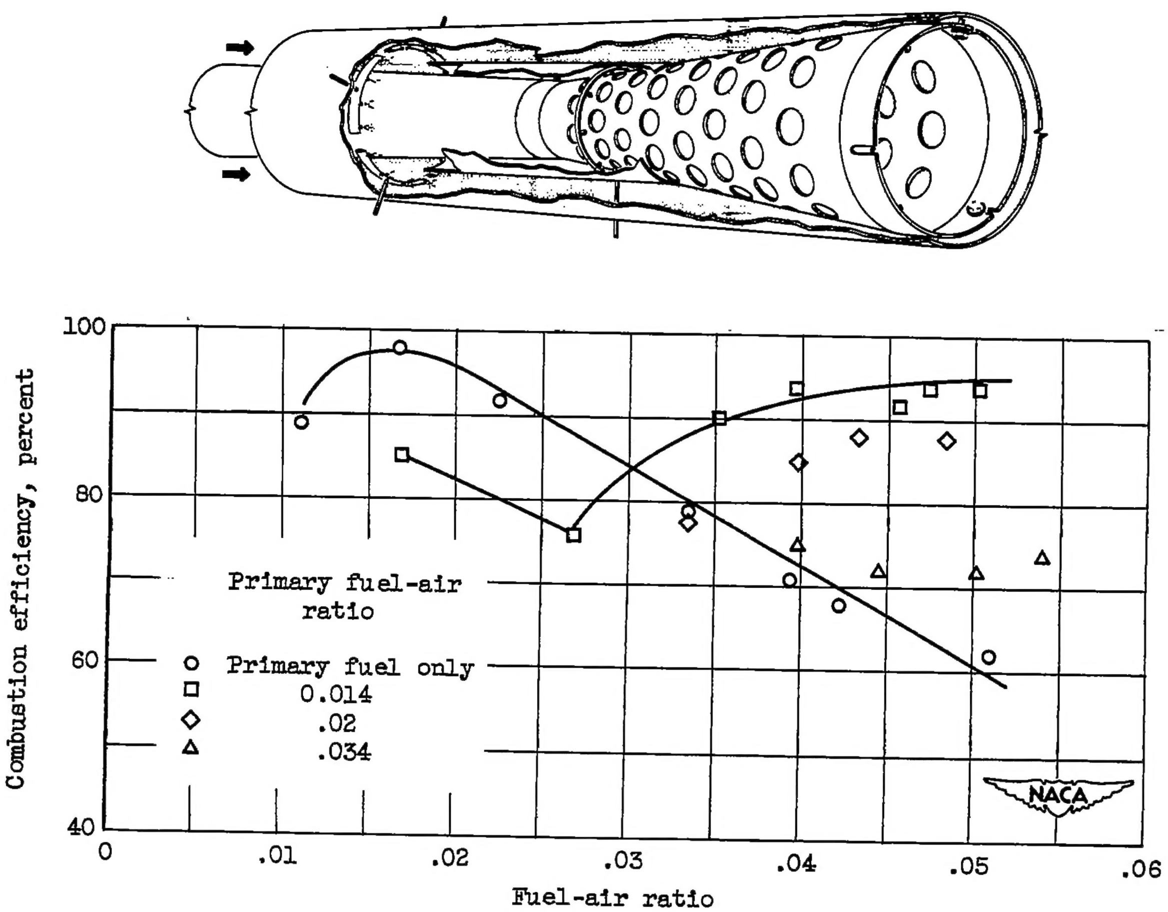

(a) Configuration F.

Figure 9. - Combustor performance of configurations F, G, H, and I with MIL-F-5624A grade JP-4 fuel. Inlet-air temperature, 590° to 610° F; velocity, 230 to 260 feet per second; pressure, 32 to 36 inches of mercury absolute.

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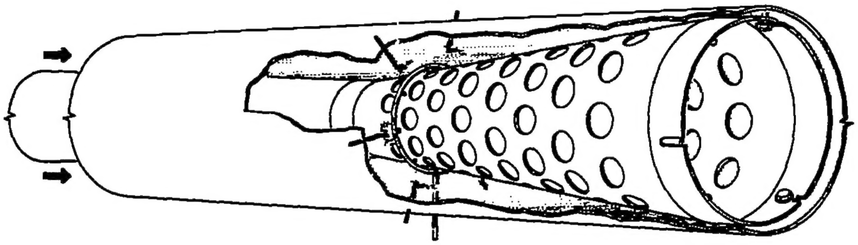
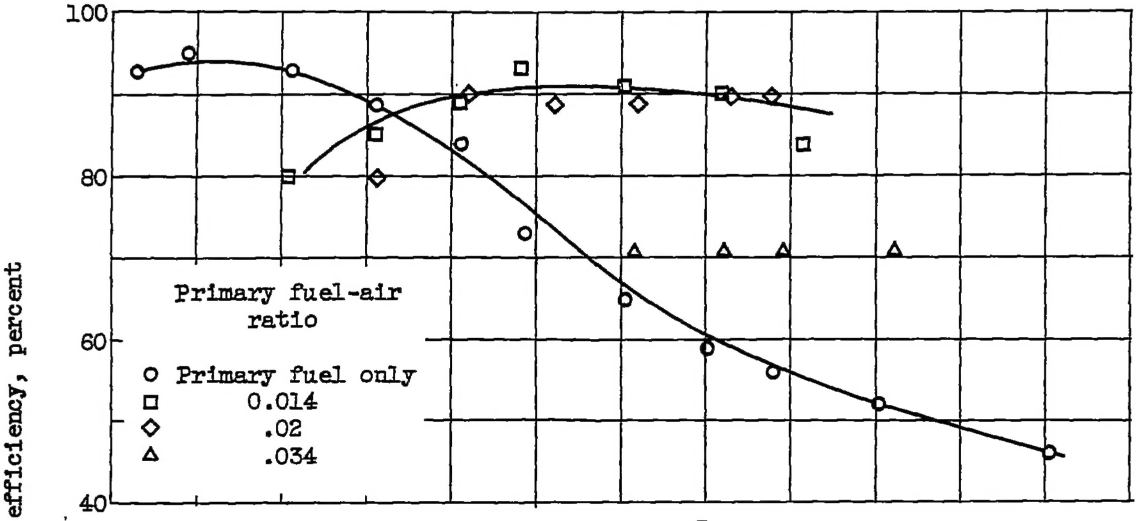
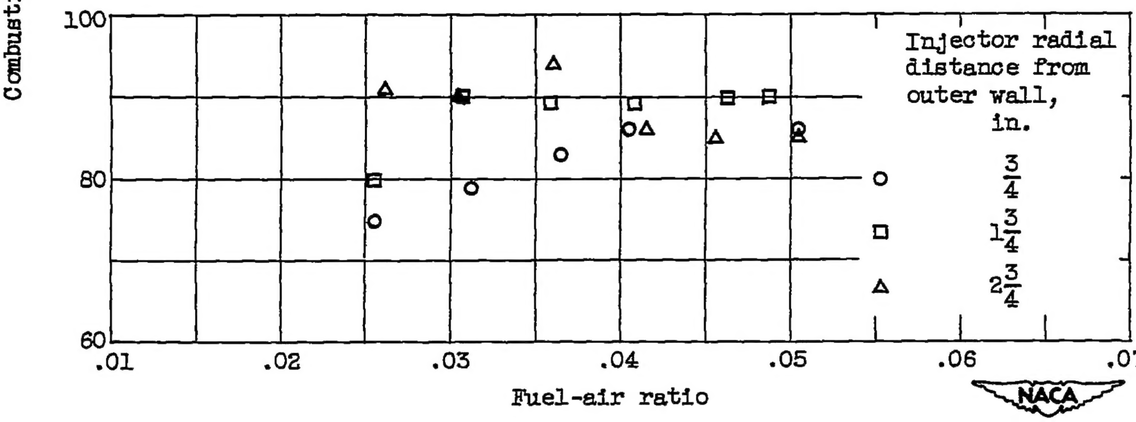




(b) Configuration G. Fuel injector $1\frac{3}{4}$ inches from outer wall.



(c) Configuration G. Primary fuel-air ratio, 0.02.

Figure 9. - Continued. Combustor performance of configurations F, G, H, and I with MIL-F-5624A grade JP-4 fuel. Inlet-air temperature, 590° to 610° F; velocity, 230 to 260 feet per second; pressure, 32 to 36 inches of mercury absolute.

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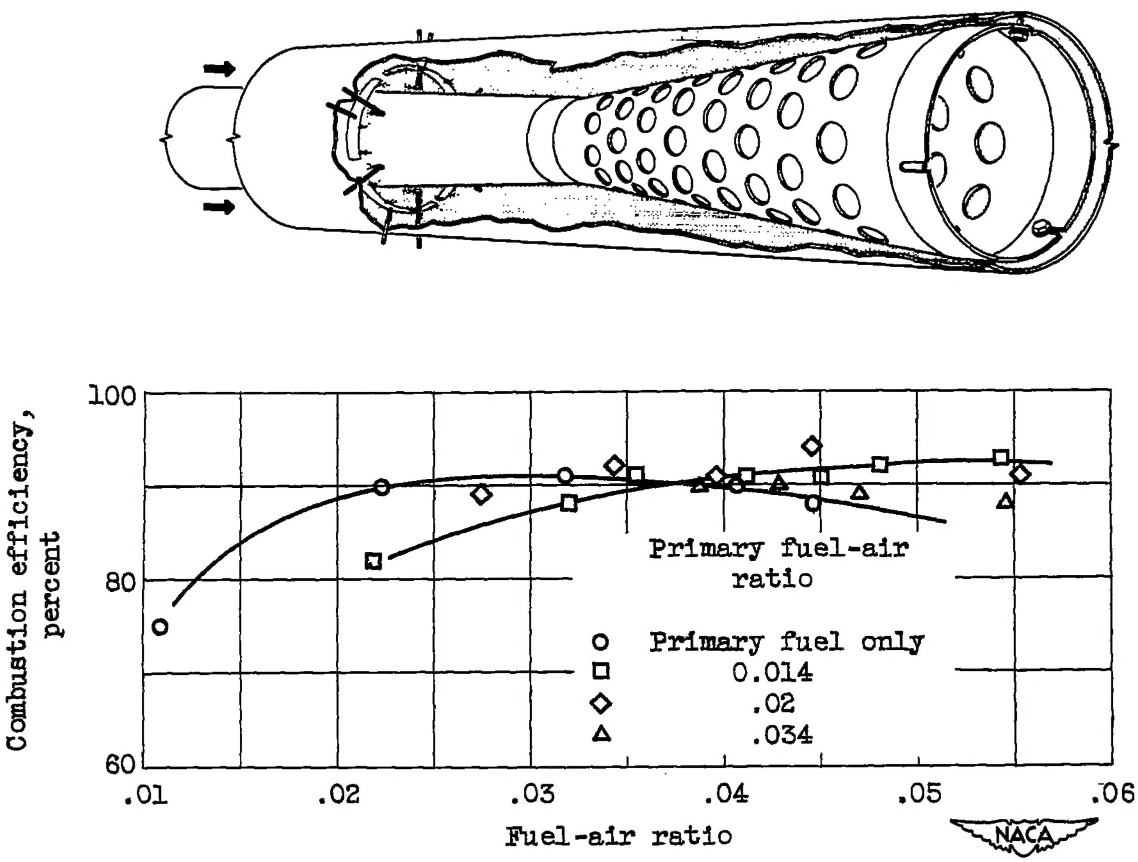

(d) Configuration H.

Figure 9. - Continued. Combustor performance of configurations F, G, H, and I with MIL-F-5624A grade JP-4 fuel. Inlet-air temperature, 590° to 610° F; velocity, 230 to 260 feet per second; pressure, 32 to 36 inches of mercury absolute.

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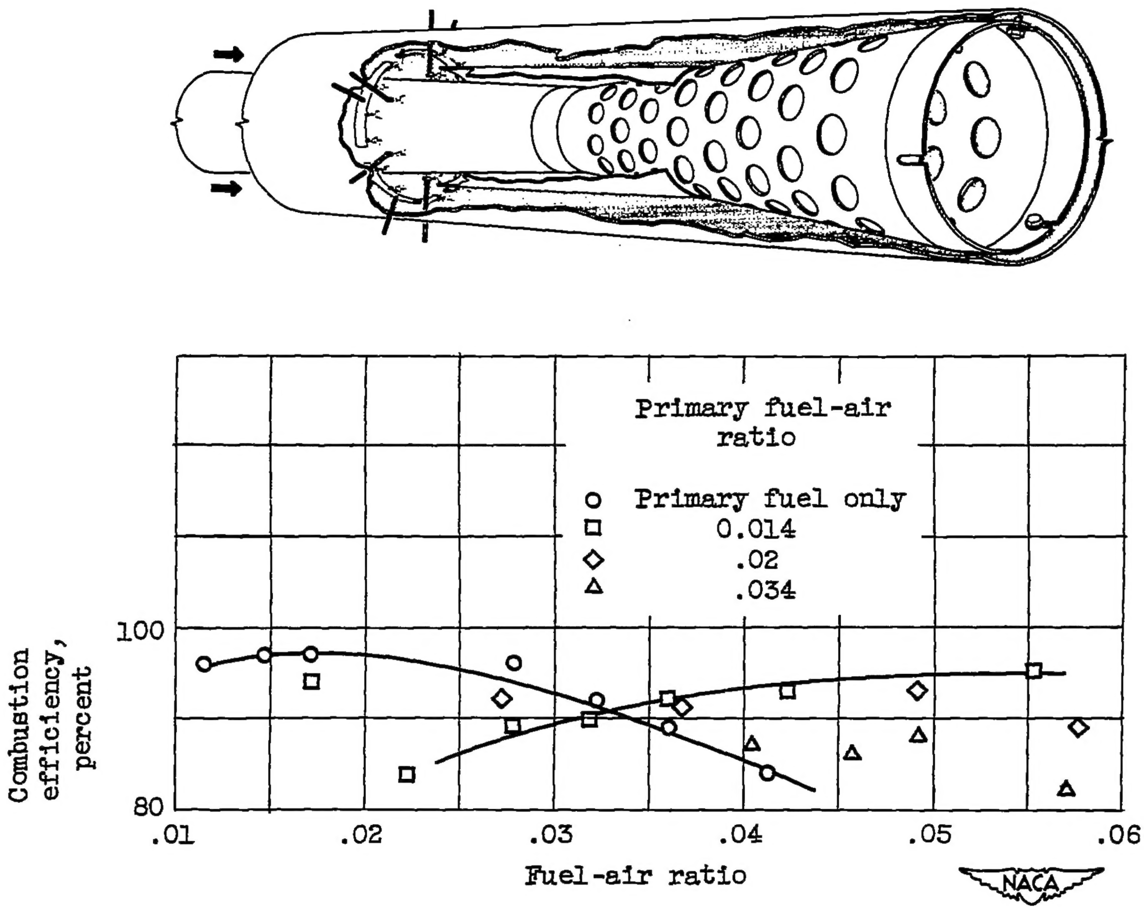

(e) Configuration I.

Figure 9. - Concluded. Combustor performance of configurations F, G, H, and I with MIL-F-5624A grade JP-4 fuel. Inlet-air temperature, 590° to 610° F; velocity, 230 to 260 feet per second; pressure, 32 to 36 inches of mercury absolute.

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